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Design evaluation and material selection of a mulch milling cutter working bodies

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Abstract. Working bodies of agricultural machinery and equipment are operated in harsh conditions. Mulching cutters shred various types of vegetation, including stumps, trees, bushes, their roots and mix wood residues with soil, which acts as an abrasive. Therefore, great attention is paid to the scientifically based selection of materials for the manufacture of the working parts of the mulching cutter. This study presents a systematic analysis of the operating conditions and design features of the working parts of the mulching cutter. The results of chemical and metallographic analysis, and hardness measurements of materials used for parts that make up the mulching cutter's working body, as well as for obtaining permanent connections between structural elements, are given. Practical recommendations for material selection that meet the required operational characteristics of the working parts in the operating conditions have been formulated.

1 Introduction

Currently, there is a multifaceted urgent problem of meeting the growing need of agriculture for modern and high-quality equipment [1]. In particular, mulchers on tractors, excavators and mini loaders are becoming more and more demanded and popular as a type of attachment equipment. The range of their application is very huge and can include: returning land to crop rotation; shredding brushwood to form organic fertilizer; primary forest clearing; territory maintenance with periodic clearing; creating mineralized strips (glades/fire lines); laying gas and power lines; other works related to shredding wood and shrub vegetation [2].

Mulching cutter (mulcher) is a special equipment, which can quickly cut vegetation together with the root, shred different types of vegetation, including stumps, trees, bushes, mixing them with the ground. Today the market for these machines is very diverse, and manufacturers offer mulchers with different characteristics and features in use [3]. The mulcher consists of a massive rotor, which has a horizontal axis of rotation, and cutting

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interchangeable working tools. The rotor and working bodies are the main working assembly units, limiting the mulcher cutter life. Working bodies for mulchers are available in a large variety of designs and can be of several types. The most popular are the working bodies that are rigidly attached to the rotor. They are called fixed and have carbide elements. These bodies are made in a large variety of designs.

Working bodies of agricultural machinery and equipment are operated in harsh conditions [4]. Mulching cutters shred various types of vegetation, including stumps, trees, bushes, their roots and mix wood residues with soil, which acts as an abrasive. Contact with rocks of various sizes is possible. Therefore, the selection of materials in the design and technology for the mulch cutter bar work tools requires special care. The market for mulch milling cutter implements is highly competitive, so manufacturers are faced with the challenge of not only meeting customer requirements, but also reducing production costs, which requires constant improvement in technology and product quality. The potential owner of mulcher equipment carefully examines the type of cutting elements, as it is one of the fundamental points and often chooses carbide. Such cutting elements for mulcher have high resource, don't need sharpening, are not afraid of small stones in the soil.

Thus, market demands on modern manufacturers of specialized machinery and equipment are constantly increasing. Consumers need construction materials that can improve the performance characteristics of products, reduce the cost of its use, reduce material intensity and extend service life [5]. Increasing the service life of wearing parts of machines is the most important problem of modern mechanical engineering. Insufficient service life reduces the economic efficiency of machines and industrial equipment application and leads to irretrievable material losses.

In light of this, the urgent task at hand is to develop approaches for selecting materials to manufacture mulch milling cutter working bodies that provide sufficient strength and wear resistance while maintaining the quality of mulch milling. In this work, we conducted an attestation of materials used for manufacturing the main cutter, side cutters with scrapers, and the mulch cutter holder.

2 Analysis of operating conditions and evaluation of working bodies design

The operating conditions of mulch cutter heads can be quite varied and depend on many factors, such as soil type, moisture, presence of stones, stems and other materials, working speed, cutting height, working depth and others. Some general operating conditions can be identified that are important to consider when selecting mulch cutter bar material and design. Working bodies of the mulching cutter are constantly exposed to mechanical loads and wear from collisions with stones, roots and other solid objects in the soil. Therefore, when selecting a material for the tools, it is important to consider its strength, wear resistance and resistance to damage. If the mulch cutter works in a wet environment or encounters aggressive chemical media such as fertilizers or pesticides, it is important to consider the material's resistance to corrosion. In addition, mulch cutter blades can get hot during operation, which can lead to deformation and degradation of the work quality, so when choosing a material, its thermal resistance and thermal conductivity must be considered. The operating speed of the mulch cutter can also have an effect on the wear and durability requirements of the cutter bar. Consideration of these conditions is necessary to select the optimal material and design of the mulch cutter bar, providing the best performance and durability with minimal maintenance and repair costs.

The tools investigated for the mulching milling cutter include a main cutter (Figure 1) or a left/right side cutter with scraper (Figure 2), a cutter holder (Figure 3) and a bolt with a nut for their connection. The complete cutting tool (the pick is pre-fitted to the toolholder with a bolt and nut) is installed by welding the toolholder to the rotor body.

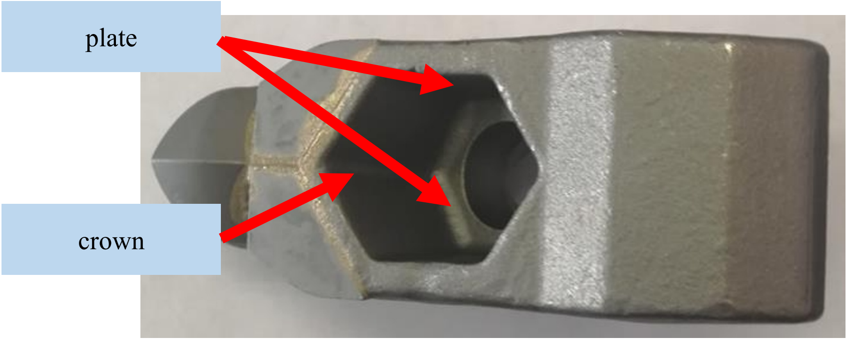

Fig. 1. Main cutter.

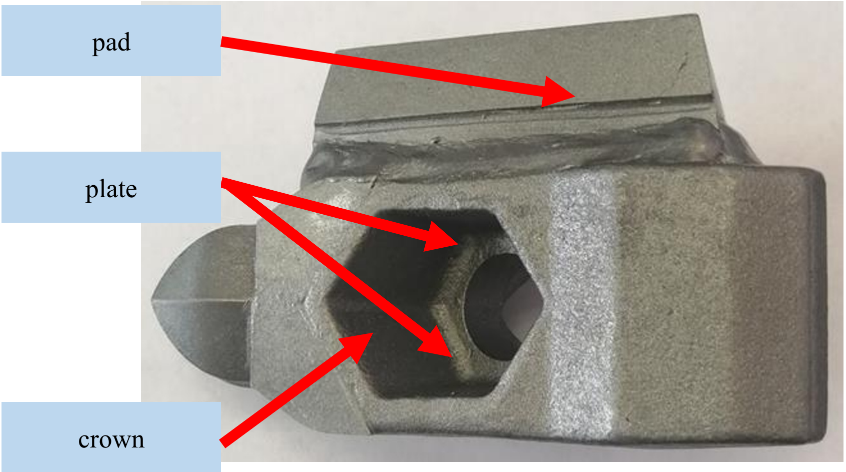

Fig. 2. Left side cutter with scraper.

Fig. 3. Cutter holder.

There are three elements (crown and two plates) soldered on the main cutter (Figure 1). Side cutters are used on the mulch cutter in two designs. In particular, they differ only in the

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position of the scraper, left or right, which is used to remove plant debris from the end surfaces of the mulcher body. For the production of lateral left and right cutters, the base of the main cutter is used as a blank. There are 4 soldered elements on the side left or right cutter (Figure 2). Three of these are soldered in the same way as the main cutter. Another pad is soldered to the scraper, which is welded to the base.

3 Material Selection of a Mulch Milling Cutter Working Bodies

The mulch cutter working bodies is made of different materials depending on the requirements for strength, wear resistance, corrosion resistance and other characteristics. One of the most common materials is high quality carbon steel, for example, 65G steel. Steels with the addition of chromium or tungsten can also be used to improve performance. Another popular material for making mulch cutter workpieces is carbide materials such as tungsten carbide, which have high hardness and wear resistance. Ceramic or composite-based materials can also be used.

To analyze the possibility of replacing the materials of the mulch milling cutter's working bodies, attestation was performed. Chemical and metallographic analyses were carried out, Vickers and Rockwell hardness of alloys were determined. We used emission spectrometer ARGON-5SF with analytical software, metallographic microscope "Altami MET 1D" with software Thixomet PRO, Vickers hardness tester Q60A+, Rockwell hardness tester TR 5006 M.

According to the content of chemical elements, the material of "Cutter holder" part corresponds to 35GL steel, the material of "Main cutter" and "Left side cutter" part bases corresponds to 40KhL steel, the cleaner of "Left side cutter" part corresponds to 45L steel. Results of hardness measurement are given in Table 1, in which the heat-affected zone is designated as HAZ. The hardness of the part "Cutter holder" was 51 HRC. The solder joint on the parts "Main cutter" and "Left side cutter" is irregular, there are pores and tears. Crowns and plates are soldered unevenly.

Table 1. Hardness of elements of parts "Main cutter" and "Left side cutter".

Part	Hardness $HV_{0,1}$
"Main cutter"	431-444 (base)
	310-354 (HAZ)
	130-135 (solder)
	1074-1076 (crown)
	1068-1073 (plate)
"Left side cutter"	633-710 (base)
	377-471 (HAZ)
	133-147 (solder)
	1062-1078 (crown)
	405-467 (joint-welding)
	330-351 (welding material)
	205-221 (scraper)
	1068-1075 (plate)

The results of the microstructure study are presented in the Figures 4-6.

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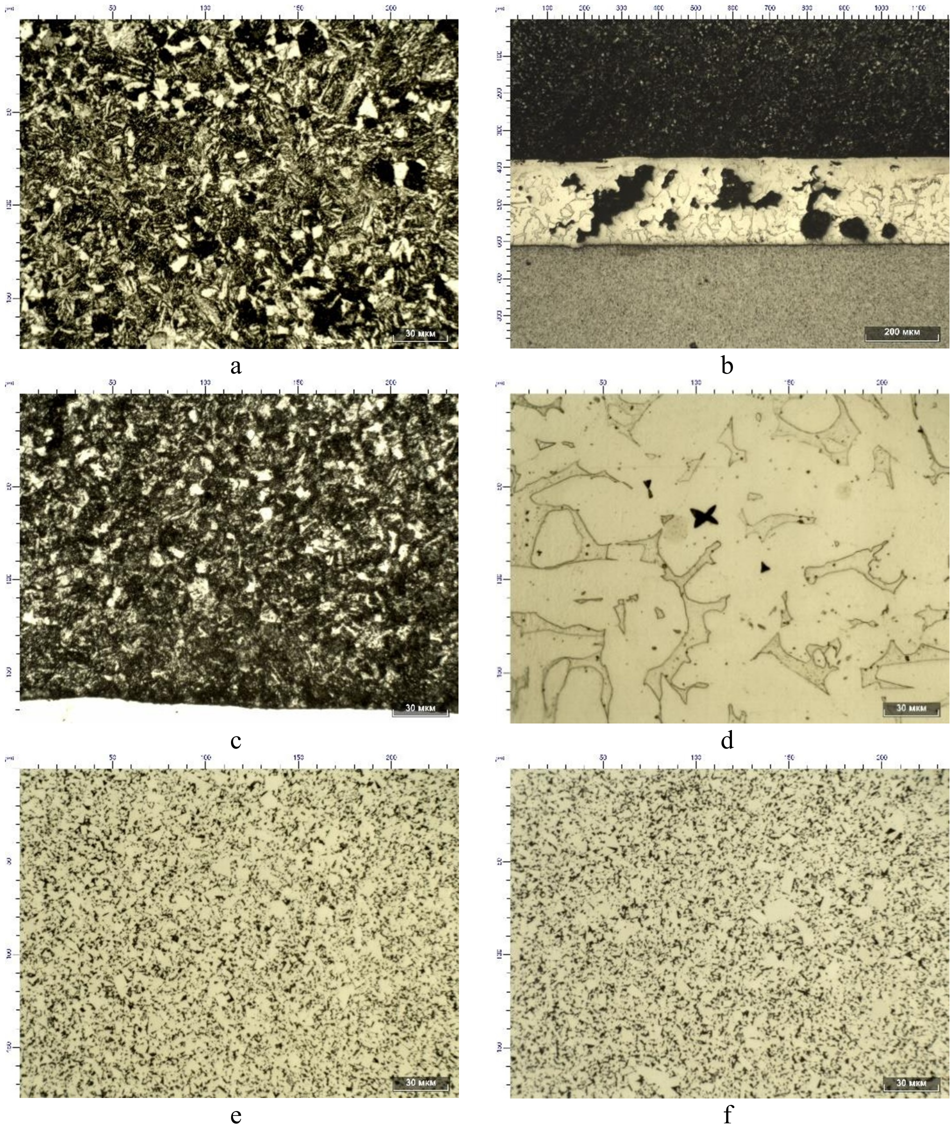

Fig. 4. Microstructure of the part "Main cutter": base (a), soldered joint (b), HAZ (c), solder (d), crown (e), plate (f)

The structure of the base of "Main cutter" part consists of martensite, ferrite, and pearlite (grain size 9-10 number). The brazed seam is irregular, with pores and tears inside. The structure of the heat-affected zone consists of sorbite, ferrite, and martensite, the proportions of which are much lower than in the base metal. The solder structure comprises the α and β'-phases as well as unidentifiable inclusions. The crown and plate structures consist of tungsten carbide distributed in a bonding cobalt phase. The tungsten carbide particles in the plate structure are larger than those in the crown structure.

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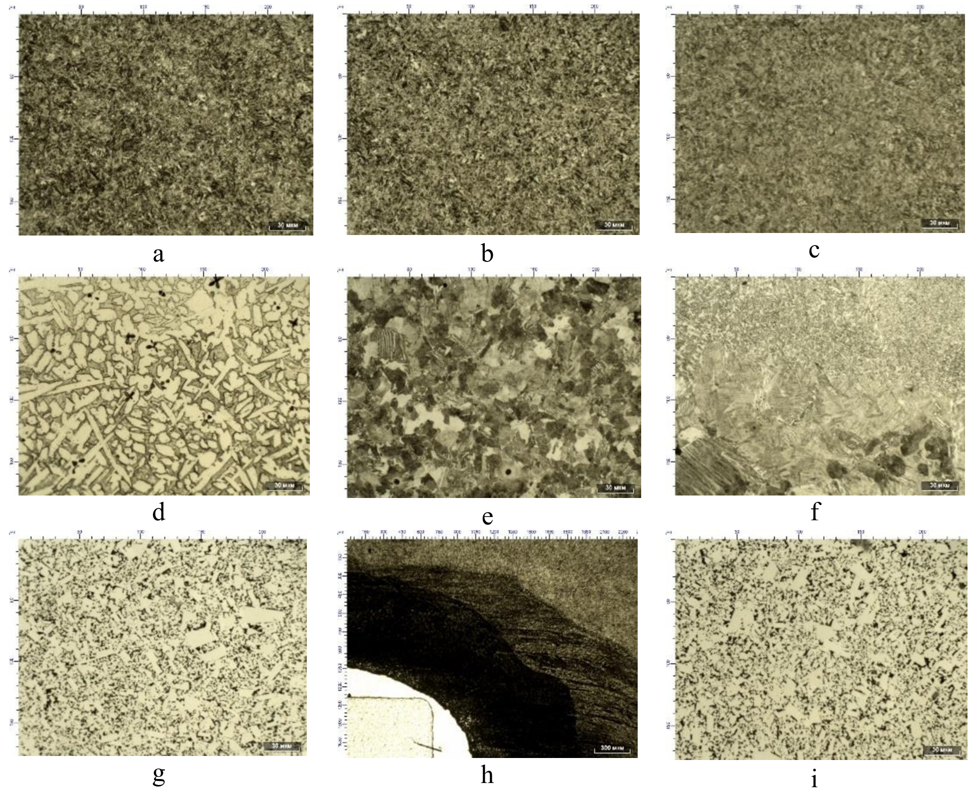

Fig. 5. Microstructure of the part "Left side cutter": base (a-c), solder (d), scraper (e), weld joint (f), crown (g), HAZ (h), pad (i)

The base structure of the part "Left side cutter" consists of bainite and martensite (grain size 9-10 number). The structure of the purest consists of pearlite and ferrite. The solder structure consists of α and β'-phase as well as unidentifiable inclusions. The weld joint and material structures consist of fine-needle and coarse-needle martensite, respectively. The crown and liner structures consist of tungsten carbide distributed in the bonding cobalt phase. The heat-affected zone is heterogeneous and the structure consists of sorbite.

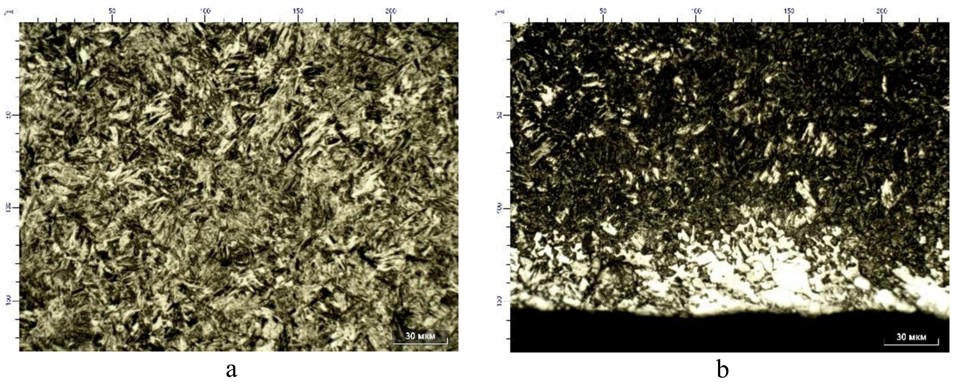

Fig. 6. Microstructure of the part "Cutter holder": main material (a), decarbonized layer (b)

The structure of the part "Cutter holder" consists of large-needle martensite of grade 8, grain size 10 number. The depth of decarburized layer on the surface of the part is 0.08 mm.

The results of attestation, together with the analysis of the operating conditions of parts and their design, allows to recommend the following materials and technologies for manufacturing parts of mulch cutter working bodies (material grades are written in accordance with Russian standards):

1) cutter holder and base – steel for castings ordinary 40KhL or ordinary steel for castings 35GL; scraper – chrome steel 40Kh or manganese steel 35GL, according to the ordinary steel grade for castings. The base metal is recommended to undergo thermal improvement, consisting of hardening and low tempering for stress relief;

2) carbide elements of cutters (crown, plates, pad) – tungsten sintered alloys of VK8, VK10 grade;

3) solder brand for soldering of carbide elements of cutters to the base and to the brush – brass and brass-nickel alloys, for example, LOK 59-1-0.3. To reduce the probability of defects in the soldered joints, soldering should be performed by induction heating with high frequency currents.

It is expedient to consider the possibility of using for brazing hard-alloy elements solders of LNMz 49-9-0.2, MNMz 55-6-4 and MNMz 9-23.5, which provide high strength of steel-solid alloy connections (350-450 MPa, depending on solder grade) and are used for the production of rock destruction tools, and also heavy-loaded tools, including road cutters for asphalt removal.

4) The grade of the electrode material used to weld the scraper to the cutter base could not be identified from the chemical composition. The weld metal is strongly mixed and extremely heterogeneous in its chemical composition.

It is expedient to use the technology and welding materials for welding of the scraper to the pick base similar to those used for welding of the pick holder, previously connected to the main or side left or right pick by means of a bolt, to the rotor body. For example, first the root welds are welded with solid wire Sv-08G2S semi-automatic gas (10% argon and 90% carbon dioxide) welding. Then root seams are surface hardened with Kiswel K-700HT flux-cored wire by semi-automatic gas welding (10 % argon and 90 % carbon dioxide). This wire is used for products requiring protection against severe mechanical wear of metal with a martensitic structure and is used in the manufacture of crusher hammers, ore-dumps, bulldozer blades, ripper teeth, excavator parts, etc. It provides the hardness of 60 HRC. Or as a substitute for it can be used welding flux-cored wire VELTEK-N565, which is used for hard-facing of mining equipment, impact drilling bits, screens, augers, parts of high-manganese austenitic steels and steels of the grades 20, 30, 35, providing the hardness 54...60 HRC.

The further direction of development of the stated approaches can be the implementation of new metal matrix composites in the practice of manufacturing products for machines and mechanisms for agricultural purposes. The prospects of research in this direction are caused by the possibility of a considerable increase in the wear resistance of products in conditions of dry and abrasive wear at the use of such materials.

4 Conclusions

Based on the analysis of operating conditions and design features of the working parts of the mulching cutter, together with experimental data on the structure, chemical and phase composition, as well as material hardness, practical recommendations for selecting material grades for the manufacture of products that meet the required operational characteristics have been developed.

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